FEATURE

Fantesk: carbohydrate–oil composites useful in low-fat foods, cosmetics, drugs and industrial applications

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An extremely stable emulsion of oil, water, and carbohydrate can be produced by co-cooking an aqueous pre-mixture of carbohydrate and oil in an excess steam jet-cooker. The resulting composite is a slippery free-flowing liquid that sets up to a soft gel on cooling or produces a free-flowing dry powder upon drum drying. Both the liquid gel and the dry powder contain micro-encapsulated droplets of oil (1-10 μm diameter) and are effective replacements for fats in dairy, baking, and meat applications, as adhesives for particle board, plywood, and paper bags and as a water-based delivery system for industrial coatings, in seed coatings laced with pesticides, herbicides, and growth regulators, and in cosmetics and drug delivery systems.

Introduction

Reduction of the amount of fat in our diets has received considerable attention recently. Recommendations from government agencies and health organisations suggest that we should consume less than 30% of calories from fat. To meet these goals, the food industry has introduced approximately one thousand new lower-fat products since the early 1990's. These products are primarily based on carbohydrates, protein, or modified fats.

Recently, we reported on a new type of fat replacer which is based on a combination of carbohydrate and small amounts of fat (1–3). This material is a new type of stable emulsion produced by jet cooking a combination of starch, water and various lipids. The resulting aqueous dispersions are stable, and the oil and water phases do not separate on prolonged standing. Freshly cooked dispersions, containing 10–20% solids, form soft gels upon standing that can be easily converted to pourable fluids by the application of heat and reformed into soft gels by cooling. The aqueous composites, which may contain up to 50% of oil based on starch content, can be air-dried into films or drum/spray-dried into flakes or powders which are not oily to the touch. Dried compositions hydrate readily and are easily dispersed in water to form smooth, lump-free dispersions similar in nature to the original composites. The nature of these emulsions make them suitable for a number of food and industrial applications, including uses in low fat dairy and meat products, adhesives, foams, cosmetics and drug delivery systems.

Preparation and physical properties of Fantesk

Stable and non-separable compositions comprised entirely of starch, water and oil can be prepared without dispersant or emulsifiers by passing a continuously stirred suspension of granular, unmodified starch and oil in water through an excess steam jet cooker. Typical production runs using this type of jet cooker produce temperatures of 140°C (285°F) and considerable turbulence and shearing from the pressure drop across the hydroheater. The residence time of the mixture of starch, oil, and water is approximately 1–2 seconds. The oil and starch/water may also be separately co-injected into the hydroheater portion of the cooker to yield a similar product.

A variety of starches and lipids can be used to produce compositions with starch-to-lipid ratios ranging from 100:5 to 100:75. Starch sources include those from corn (maize), wheat, rice and potato, and the amylose/amylopectin ratios may be varied over a broad range. Lipids include vegetable oils and fats, animal oils and fats, and various petroleum-based products. A portion of the jet-cooked product may also be recycled into the original mixing chamber to pre-emulsify the starch, water, and oil components. This 'addback' procedure results in a product with smaller and more uniformly-dispersed oil droplets.

The viscosities of jet-cooked dispersions are determined by solids content. At room temperature, the viscosities range from free-flowing liquids at about 5% solids to soft gels at 20% solids. Increases or decreases in temperature cause corresponding changes in fluidity and gelling properties. The dispersions may also be drum-dried to yield solid compositions that are not oily to the touch and may be readily rehydrated to give compositions similar to the original.

The presence of oil in these composites also facilitates the incorporation of additional amounts of water-insoluble materials, such as volatile essential oils and food flavouring materials, antioxidants, pharmaceuticals and agricultural chemicals. These properties also lend themselves to the formulation of seed coatings, glues and adhesives, cosmetics, and drug delivery systems.

Microstructure

The detailed microstructure of solvent-extracted thin films of these starch-oil composites are shown in photographs taken using a scanning electron microscope (***Figure 1***). The size and distribution of cavities formerly occupied by microdroplets of lipid increases with the amount of oil that is incorporated. We show typical composites with 5, 20 and 40 parts oil per 100 parts starch in ***Fig 1, A–C***.

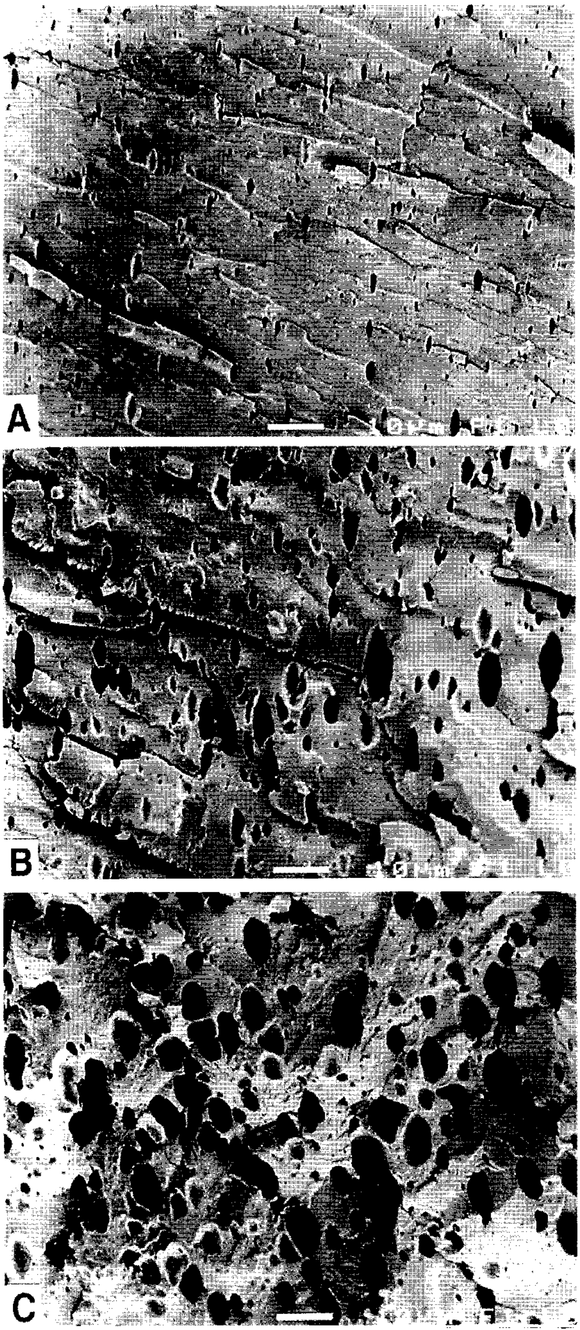

Figure 1. Scanning electron micrograph of fracture face of: (A) starch–oil composite (100 parts starch, 5 parts soybean oil) dried to film and extracted with ethanol followed by hexane; (B) starch–oil composite (100 parts starch, 20 parts soy oil; (c) starch–oil composite (100 parts starch, 40 parts soybean oil). Dark areas are cavities formerly occupied by microdroplets of lipid.

Photographs of aqueous composites taken with a light microscope show similar size and distribution of microencapsulated oil droplets (see ***Figure 2, A–C***). A detailed photograph of a fixed thin slice of an aqueous gel taken using a transmission electron microscope shows a unique boundary surrounding each oil droplet (***Figure 3***). In all the photographs, the starch matrix is rigorously excluded and does not penetrate the boundary layers. Although adjacent droplets may be close to one another, there is no apparent coalescence or merging of boundary layers. This may explain the observed stability of the starch, oil, water emulsions formed by our process. It also suggests that there are exciting possibilities of using these microdroplets of oil as liposomes, microencapsulating agents, and drug delivery systems, in which targeting information is embedded in the boundary material surrounding the oil droplets.

Extraction of oil from Fantesk

The starch-oil composites are resistant to separation of the hydrophilic and hydrophobic phases in the solid state and over a wide range of aqueous dilutions. Dry samples can be extracted with hexane and the hexane evaporated to determine the amount of extractable oil. The extracted samples are then dispersed, hydrolysed with amylase, and re-extracted with hexane to determine the amount of tightly bound oil. The amounts of 'loosely bound' and 'tightly bound' oil in various composites determined by hexane extraction of the drum dried powder are shown in ***Table 1***.

The content of tightly bound oil from composites having 20 or 40 parts of oil per 100 parts of normal corn starch are similar (4–6% of total sample weight). However, in various starches or mixtures of starches, the proportion of tightly bound oil increases with increased amylose content.

Aqueous dispersions of Fantesk reconstituted from drum-dried material are much more resistant to extraction with hexane than simple mixtures of oil and gelatinized starch containing equivalent proportions of oil. More than 90% of the oil can be extracted from gelatinized starch–oil mixtures with five extractions, whereas the jet cooked starch–oil composite containing 40 parts of oil loses less than 30% of its oil in 8 extractions. This retention of oil in aqueous composites increases with the amylose content of the starch and with the solids content of the aqueous composite.

Table 1. Composition of jet-cooked starch-oil composites (dry weight basis).

Starch	Oil added		Starch in sample (%)	Amylose in starch (%)	Recovered oil (% product wt)		
	g/100 g of starch	% wt of product			total	loosely bound	tightly bound
Normal	20	16.7	80.3	21.5	12.8	6.7	6.1
Normal	40	28.6	80.3	21.5	23.9	16.8	7.1
Waxy	40	28.6	80.7	0	23.4	19.1	4.3
Amylomaize	40	28.6	82.1	66.8	22.7	14.3	8.4

Technology transfer and applications

Starch-oil composites are suitable for applications which require aqueous delivery of oils and organic materials. We discuss a number of such applications in the following pages.

Food applications

Co-jet cooking can be carried out with food-grade starches and with commercial oils and lipids commonly used in food products — for example, corn oil, soybean oil, butter and animal-derived fats. Lipid-to-starch ratios can be varied over a broad range in order to optimise the properties of the resulting composite for the specific application desired. Composites are added to food products either as drum-dried or spray-dried powders, as reconstituted dispersions prepared by adding dried composites to water, or as undried dispersions collected directly from the jet cooker.

One area of application is the use of starch–lipid composites as fat substitutes. Fat substitutes are used extensively in dairy products, such as ice cream, soft-serve ice milk, cottage cheese, low-fat cheese, and yogurt. They are also added to low-fat meat products to improve flavour, juiciness and texture. Low-fat confectionery products, such as cream-filled candy is another obvious area of application for fat substitutes of this type. The use of these composites as components in low-fat salad dressings is also possible. Although Fantesk contains fat, only small amounts of it are necessary to impart the taste and mouthfeel of much larger amounts of fat. Thus, ice cream containing 0.5% fat and sausages containing 2.8% fat are very good when this fat is delivered by Fantesk.

The baking industry also provides a large potential market for these starch–lipid composites. Dried composites can be added to instant cake formulations as a replacement for some or all of the shortening that is typically used. Composites can also be used as fat replacements in high-fat baked goods, such as cookies, pastries, and biscuits.

Another potential use for starch–lipid composites is as a coating for microwave popcorn. Preliminary tests in our laboratory have shown that water dispersions of starch-lipid composite can be used to coat popcorn and, when dried, form a uniform coating on the surface of the

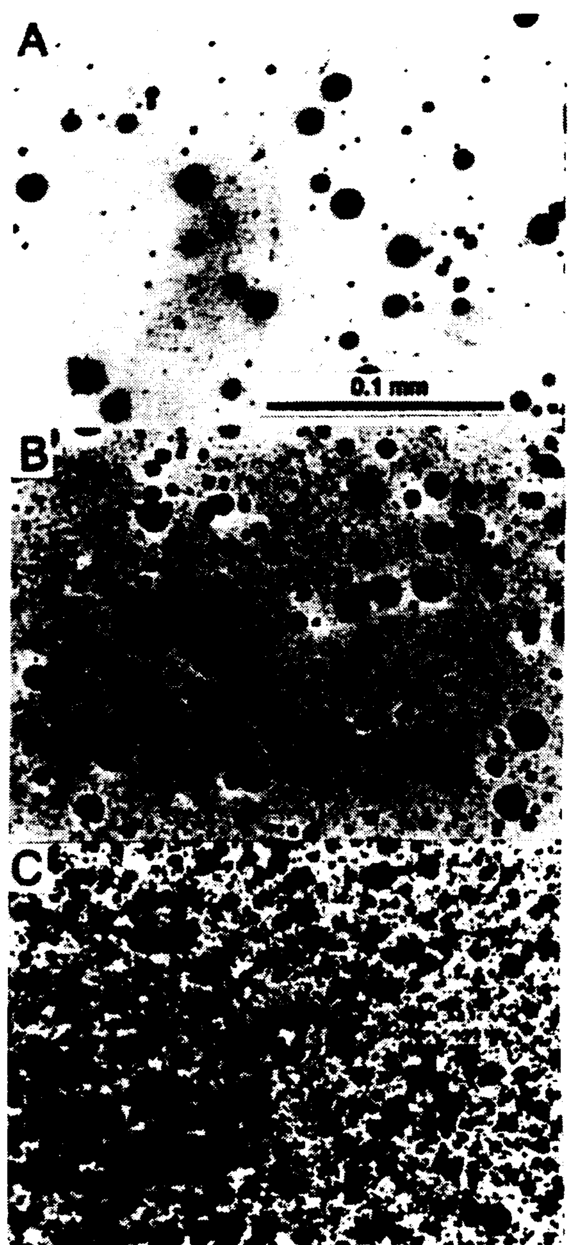

Figure 2. Light micrograph of fixed, dehydrated, embedded, and sectioned samples of reconstituted starch–oil composite gels: (A) 10 parts soybean oil; (B) 20 parts soybean oil; (C) 40 parts soybean oil co-cooked with 100 parts of starch. Dark areas are droplets of lipid.

Figure 3. Transmission electron micrograph of starch–oil composite gel showing compression of adjacent oil droplets and lighter-staining border layer.

kernel. Because of the presence of the lipid component, this coating does not separate easily from the waxy seed surface, but adheres tenaciously, even after rough handling of the coated seeds. Popcorn coated with Fantesk pops readily in a microwave oven and yields only a few unpopped kernels. An added benefit of using starch–lipid composite to coat popcorn is the ability of the composite to accept oil-soluble flavouring materials, such as butter, cheese, onion, and garlic and to transmit these flavours to the popped kernels.

Finally, the presence of the oil component in our composites makes these products extremely receptive to the addition of many essential oils and flavourings commonly used in food formulations. Even though many of these oils and flavourings are quite volatile, they remain entrapped within the starch–lipid matrix, even after drying, and are released only when the dried starch–lipid composite is broken, scratched, or re-dispersed in water. Composites of this type are therefore excellent flavour carriers in food products.

Adhesives and coatings for industrial applications

Fantesk containing natural resins has been tested in adhesive formulations for the production of plywood, particle board, and box board. Phenol–formaldehyde resins are currently used for plywood production, whereas, urea-formaldehyde resins are used for particle board. Use of a low-cost starch–lipid composite in these formulations would not only provide an economic advantage, but would also reduce the amount of highly toxic formaldehyde and phenol used in these applications. Moreover, starch in these adhesive formulations should act as a scavenger for free formaldehyde and should therefore reduce the chance that toxic formaldehyde will be released from finished products when they are used by the consumer.

Cosmetic and medicinal applications

Since starch–lipid composites have a smooth, creamy consistency when dispersed in water, and the lipid component does not separate on prolonged standing, there are a number of possible applications for these materials in cosmetic and drug delivery formulations.

When starches from various plant sources are co-jet cooked with paraffin oils, mineral oils, and silicone oils, the resulting aqueous dispersions are suitable as lotions and skin creams. *Alpha*-hydroxy fatty acids, vitamin E, vitamin A, β-carotene and other agents commonly used for skin conditioning can also be incorporated into these formulations.

Since the presence of the lipid component makes aqueous dispersions of these composites receptive to the addition of other water-insoluble organic materials, the use of these composites as carriers for drugs and medicinal agents is possible. In cooperation with drug companies, we will attempt to develop new and novel drug delivery systems based on these composites.

Seed coating applications

When starch–lipid composites in aqueous dispersion are coated onto seeds and the seeds are allowed to dry, a uniform coating is formed on the seed surface. The lipid component of the composite causes this coating to adhere tenaciously to the seed surface, and the coating will not flake off of the seed during the planting operation. Since the lipid component of the composite allows water-insoluble organic compounds to be blended in and yields intimate mixtures that will not separate, composites of this type function as carriers for pesticides, herbicides, and plant growth regulators. Nitrogen-fixing soil bacteria such as *Rhizobia* species can also be added to water dispersions of the composite prior to seed coating.

In addition to their ability to disperse and encapsulate agricultural chemicals and to hold these materials at the seed surface, these composites will also absorb water due to the presence of the starch component. They will therefore attract and hold water at the seed surface, thus increasing both the rate of germination and the percentage of seeds that germinate. To further enhance the water-holding properties of these coating formulations, water-absorbent polymers, such as 'Super Slurper' can also be added to the water dispersion used for seed coating.

The patented process and products are being licensed to several companies in the food, forest products, and seed coating areas. Additional contacts and working agreements are being pursued with companies involved in cosmetics, pharmaceuticals, oil drilling and machine cutting.

References

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